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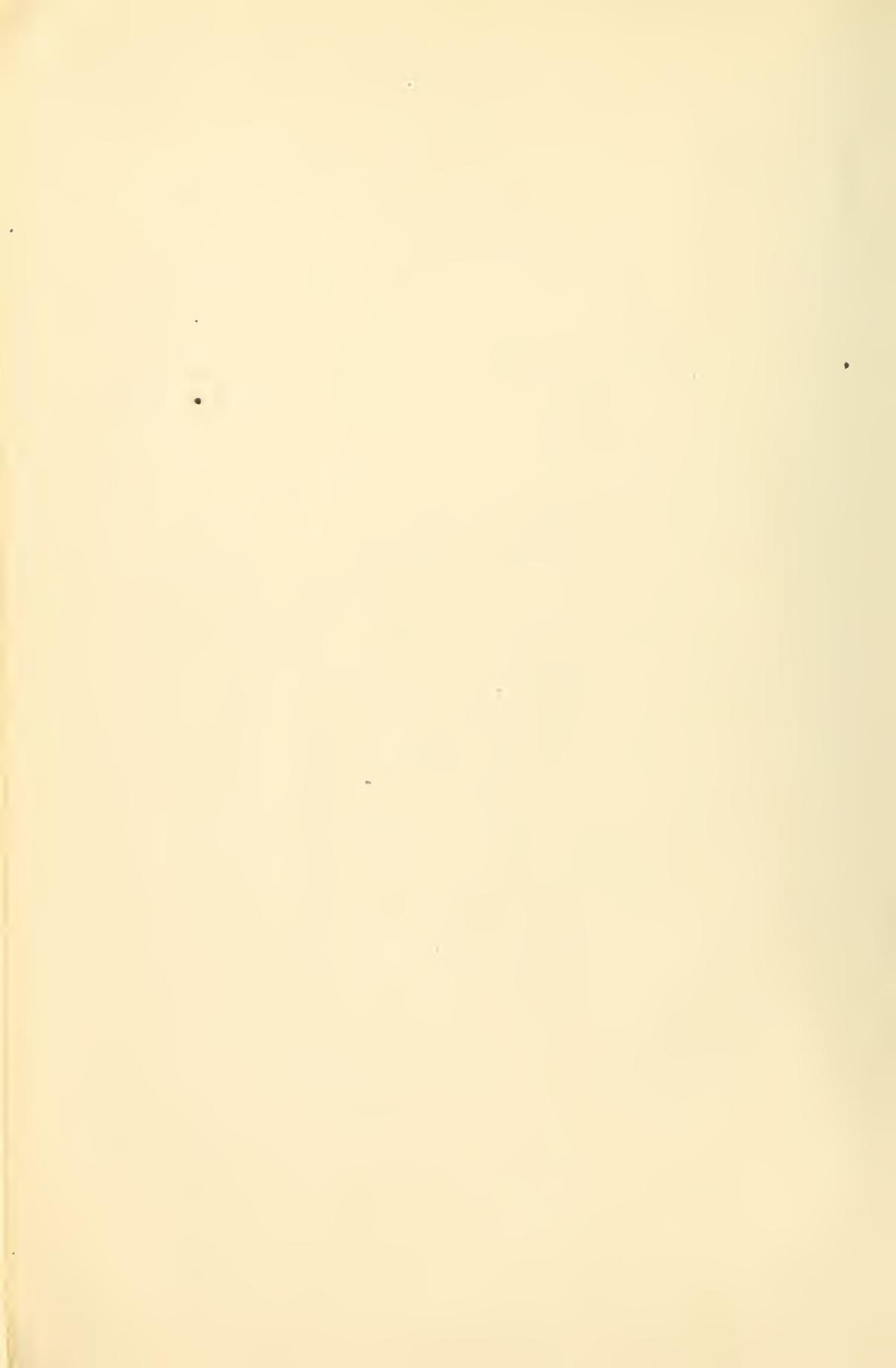
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## CONTENTS OF VOLUME 19

	Page
469. DIRECTIVE RADIO TRANSMISSION ON A WAVE LENGTH OF 10 METERS. <i>Francis W. Dunmore and Francis H. Engel</i>	1
470. A METHOD FOR THE ACCURATE MEASUREMENT OF SHORT-TIME INTERVALS..... <i>Harvey L. Curtis and Robert C. Duncan</i>	17
471. METHODS OF MEASUREMENT OF PROPERTIES OF ELECTRICAL INSULATING MATERIALS..... <i>J. H. Dellinger and J. L. Preston</i>	39
472. ALTERNATING-CURRENT RESISTANCE AND INDUCTANCE OF SINGLE-LAYER COILS..... <i>C. N. Hickman</i>	73
473. A METHOD FOR THE MEASUREMENT OF SOUND INTENSITY... <i>J. C. Karcher</i>	105
474. SERIES IN THE ARC SPECTRUM OF MOLYBDÉNUM..... <i>C. C. Kiess</i>	113
475. VISIBILITY OF RADIANT ENERGY... <i>K. S. Gibson and E. P. T. Tyndall</i>	131
476. A STUDY OF RADIO SIGNAL FADING. <i>J. H. Dellinger, L. E. Whittemore, and S. Kruse</i>	193
477. SPECTRORADIOMETRIC ANALYSIS OF RADIO SIGNALS..... <i>Chester Snow</i>	231
478. REDETERMINATION OF SECONDARY STANDARDS OF WAVE LENGTH FROM THE NEW INTERNATIONAL IRON ARC. <i>W. F. Meggers, C. C. Kiess, and Keivin Burns</i>	263
479. INTERFEROMETER MEASUREMENTS OF THE LONGER WAVES IN THE IRON ARC SPECTRUM..... <i>W. F. Meggers and C. C. Kiess</i>	273
480. A DIRECTIVE TYPE OF RADIO BEACON AND ITS APPLICATION TO NAVIGATION..... <i>F. H. Engel and F. W. Dunmore</i>	281
481. MEASUREMENT OF LOW RESISTANCE BY MEANS OF THE WHEATSTONE BRIDGE..... <i>Frank Wenner and Alva Smith</i>	297
482. GRAVITATIONAL ANISOTROPY IN CRYSTALS..... <i>Paul R. Heyl</i>	307
483. INVESTIGATION OF THE PLATINUM METALS: IV. DETERMINATION OF IRIDIUM IN PLATINUM ALLOYS BY THE METHOD OF FUSION WITH LEAD. <i>Raleigh Gilchrist</i>	325
484. PREPARATION AND PROPERTIES OF PURE IRON ALLOYS: IV. DETERMINATION OF THE CRITICAL RANGES OF PURE IRON-CARBON ALLOYS BY THE THERMOELECTRIC METHOD..... <i>J. F. T. Berliner</i>	347
485. APPLICATION OF THE INTERFEROMETER TO MEASUREMENTS OF THE THERMAL DILATATION OF CERAMIC MATERIALS..... <i>George E. Merritt</i>	357
486. SOME NEW THERMOELECTRICAL AND ACTINOELECTRICAL PROPERTIES OF MOLYBDENITE..... <i>W. W. Coblenz</i>	375
487. A QUANTITATIVE STUDY OF REGENERATION BY INDUCTIVE FEED BACK. <i>C. B. Jolliffe and Miss J. A. Rodman</i>	419
488. THERMAL EXPANSION OF MOLYBDÉNUM.... <i>Peter Hidnert and W. B. Gero</i>	429
489. PRIMARY RADIO-FREQUENCY STANDARDIZATION BY USE OF THE CATHODE-RAY OSCILLOGRAPH..... <i>Grace Hazen and Frieda Kenyon</i>	445
490. SPECTRA AND CRITICAL POTENTIALS OF FIFTH GROUP ELEMENTS. <i>Arthur E. Ruark, F. L. Mohler, Paul D. Foote, and R. L. Chenault</i>	463
491. THEORY OF DETERMINATION OF ULTRA-RADIO FREQUENCIES BY STANDING WAVES ON WIRES..... <i>August Hund</i>	487

	Page
492. FORMULAS, TABLES, AND CURVES FOR COMPUTING THE MUTUAL INDUCTANCE OF TWO COAXIAL CIRCLES. . <i>Harvey L. Curtis and C. Matilda Sparks</i>	541
493. ULTRA-VIOLET REFLECTING POWER OF SOME METALS AND SULPHIDES. <i>W. W. Coblenz and C. W. Hughes</i>	577
494. ABERRATIONS OF LONG FOCUS ANASTIGMATIC PHOTOGRAPHIC OBJECTIVES <i>A. H. Bennett</i>	587
495. A RADIOMETRIC INVESTIGATION OF THE GERMICIDAL ACTION OF ULTRA-VIOLET RADIATION. . . . . <i>W. W. Coblenz and H. R. Fulton</i>	641
496. EFFECT OF STRESS ON THE MAGNETIC PROPERTIES OF STEEL WIRE. <i>R. L. Sanford</i>	681
497. THERMAL EXPANSION OF ALUMINUM AND VARIOUS IMPORTANT ALUMINUM ALLOYS . . . . . <i>Peter Hidnert</i>	697





DEPARTMENT OF COMMERCE  
BUREAU OF STANDARDS  
George K. Burgess, Director

SCIENTIFIC PAPERS OF THE BUREAU OF STANDARDS, No. 478

[Part of Vol. 19]

REDETERMINATION OF SECONDARY  
STANDARDS OF WAVE LENGTH FROM THE  
NEW INTERNATIONAL IRON ARC

BY

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# REDETERMINATION OF SECONDARY STANDARDS OF WAVE LENGTH FROM THE NEW INTERNATIONAL IRON ARC.

By W. F. Meggers, C. C. Kiess, and Keivin Burns.

## ABSTRACT.

The system of secondary standards of wave length now in common use was derived from an axial part about 2 mm wide in the center of an iron arc about 6 mm long, and was established before the full importance of operating conditions of sources was recognized. In this type of arc certain lines, grouped as c and d lines because of their sensitiveness to pressure, appeared to be displaced with respect to others grouped as a and b lines, so that the International Astronomical Union in 1922 recommended that the length of the arc be 12 to 15 mm and that light be taken from a central zone not to exceed 1-1.5 mm in width. These changes in the standard iron arc made it desirable to redetermine the secondary standards of wave length. The well-known interferometer method of Fabry and Perot was employed to measure wave lengths of selected lines in the iron spectrum directly in terms of the primary standard, the wave length of the red radiation from cadmium which served for the wave-length meter comparisons. New results are given for 159 lines between 3370 Å and 6678 Å, including 84 of the international secondary standards. For 23 lines belonging to groups c and d, the secondary standards minus the new values averages  $+0.0072$  Å. There is also a systematic difference for lines of groups a and b, 44 such lines averaging  $0.0029$  Å less than the present international values. The reason for the latter divergence is not obvious, but it may be due to a real error in the international system, which, it is pointed out, was not established strictly according to the logical definitions of such a system nor with the accuracy which might be possible now in a redetermination.

## CONTENTS.

	Page.
I. Introduction.....	263
II. Apparatus and methods.....	264
III. Results.....	267
IV. Discussion.....	270

## I. INTRODUCTION.

An international system of secondary standards of wave length, derived from the iron arc spectrum, was established by the International Union for Cooperation in Solar Research during the years 1905 to 1913. This system comprises 86 values<sup>1</sup> extending from 3370.789 Å in the ultra-violet to 6750.163 Å in the red, and for more than a decade it has been used very extensively in spectroscopy and astrophysics. The values are based upon three independent observations by the interferometer method of Fabry and Perot, and are referred to the value 6438.4696 Å, obtained by

<sup>1</sup> J. O. S. A., 5, p. 308; 1921.

Benoit, Fabry, and Perot, for the red radiation of cadmium in terms of the meter. The actual comparisons of wave length were made before the full importance of operating conditions of sources was realized and it was not until 1913 that the iron arc in air as a source of international standards<sup>2</sup> was carefully specified as follows: Length of arc 6 mm; current of 6 amperes for wave length greater than 4000 Å, 4 amperes or less for wave lengths shorter than 4000 Å; direct current with positive pole above the negative, potential of 220 volts; iron rods of 7 mm diameter for electrodes; axial part about 2 mm wide in center of arc to be used as the source of light; only lines of groups a, b, c, d to be used as standards. Somewhat later, it was shown by investigations<sup>3</sup> at the Mt. Wilson Observatory that the lines of groups c and d were displaced toward the red in this type of arc. This displacement, affecting about 20 of the secondary standards, was regarded as a change in wave length of these lines as compared with lines of groups a and b, which were assumed to be independent of ordinary variations in the source.

In July, 1919, the International Astronomical Union was organized to replace the union which existed before the war and its transactions for 1922 contained the following statement with respect to the iron arc:<sup>4</sup>

In order to obtain lines of constant wave length, constant intensity distribution and adapted to high orders of interference, the adoption is recommended of the Pfund arc operated between 110 and 250 volts, with 5 amperes or less, at a length of 12-15 mm used over a central zone not to exceed 1-1.5 mm in width, and with an iron rod 6-7 mm diameter as the upper pole and a bead of oxide of iron as the lower pole.

In view of these radical changes in the standard iron arc, it became desirable to redetermine the secondary standards of wave length, and in this paper new results are given for 159 lines, including 84 of the international secondary standards.

## II. APPARATUS AND METHODS.

A newly constructed iron arc was used in this investigation. The arc stand without electrodes is shown in Figure 1. In order to select the proper length and portion of the arc, it is convenient to have adjustments in three dimensions as well as additional ones for aligning and separating the electrodes. Iron rods 7 mm in diameter were used as electrodes and the upper or positive pole was surrounded by a close fitting brass cylinder perforated with holes to serve as a radiator.

<sup>2</sup> Trans. I. U. S. R., 4, p. 58; 1914.

<sup>3</sup> Astroph. J., 42, p. 231; 1915; Ibid., 46, p. 138; 1917.

<sup>4</sup> Trans. I. A. U., 1, p. 36; 1922.

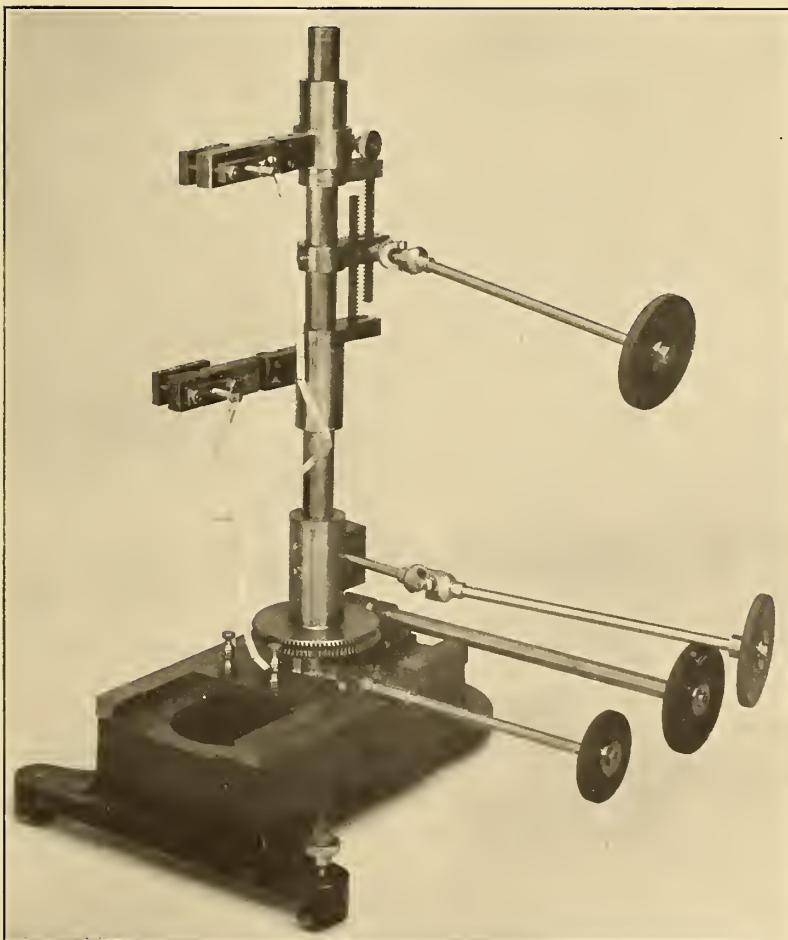


FIG. 1.—*New stand for the iron arc.*



The cadmium source was a spectrum tube of the H type similar to the one described by Michelson. This type of tube served as a source in both of the meter measurements in terms of the wave length of the red radiation from cadmium vapor, and is the one mentioned in the definition of the unit of wave length.<sup>5</sup> The International Astronomical Union has defined some auxiliary standards<sup>6</sup> in the neon spectrum as equivalent in most cases to the primary standard, and we have accordingly used neon tubes for part of the comparison exposures. Tubes similar to the one used for neon and cadmium wave-length comparisons<sup>7</sup> were employed and served in every case to determine the order of interference in the convenient manner described heretofore.<sup>7</sup>

A quartz lens projected a fourfold magnified image of the arc on the interferometer which was diaphragmed to a 6 mm aperture, the latter thus receiving light from about 1.5 mm in the center of a 12 mm arc.

Nearly half of the exposures were made simultaneously to the iron arc and the comparison sources, cadmium or neon, and in such cases the light from the arc was reflected to the interferometer by a thinly silvered mirror, through which the light from the comparison sources passed. When exposures were not made simultaneously the comparison source was photographed both before and after the iron arc, and the iron wave lengths were then derived from the mean of the two comparison exposures. An arrangement whereby exposures could be made simultaneously to three different sources, viz, iron, cadmium, and neon, was also tried, but finally discarded because of its wastefulness of light.

Two sets of interferometer plates were employed, the one set being cathodically covered with semitransparent films of silver and the other with nickel. Various separations of the interferometer plates were used in different exposures, the separators or étalons being of invar and having lengths ranging from 3 to 15 mm. The interferometer plates were mounted in the cylindrical holder described elsewhere<sup>8</sup> and the whole interferometer was slipped into a long brass tube packed in granulated cork, and thus protected from any air currents and outside temperature changes which might occur.

For dispersing the spectra the stigmatic concave grating mounting described before<sup>9</sup> was employed. The observations were made

<sup>5</sup> Trans. I. U. S. R., 2, p. 20; 1908.

<sup>6</sup> Trans. I. A. U., 1, p. 35; 1922.

<sup>7</sup> B. S. Sci. Papers, 12, p. 203; 1915.

<sup>8</sup> B. S. Bull., 14, p. 711; 1918.

<sup>9</sup> B. S. Sci. Papers, 18, p. 191; 1922.

in a basement laboratory whose diurnal temperature fluctuations are negligible, and both the arc and the cadmium lamp furnace were inclosed in ventilated hoods so that there was no difficulty with temperature effects on the apparatus.

Schleussner "ultra-rapid" plates, 40 cm long by 6 cm wide, were employed in photographing the spectra. These plates were of extra thin glass, which permitted them to be bent to the best focus for spectral lines and interference rings throughout the entire spectrum extending from about 3000 Å in the ultra-violet to about 7000 Å in the red. The end of the plate used for recording the yellow, orange, and red was sensitized by bathing in a pinacyanol solution. The light from the iron arc was passed through a Wratten minus blue filter for part of the long exposures in order that the green, yellow, and red portions of the spectrum might be more comparable with the ultra-violet in photographic density. Some extra short exposures were made in order to obtain good images of the stronger lines which were otherwise generally over-exposed, especially in the ultra-violet. A summary of the plates and data relating to them is contained in Table 1.

TABLE 1.—Summary of Observations.

Plate No.	Étalon.	Film.	Exposures of sources (in minutes).
	mm		
G 1381.....	3	Ni	Ne, 25; Fe, 40; Ne, 20.
G 1383.....	5	Ni	Cd, 25; Fe, 45; Ne, 12.
G 1384.....	7.5	Ni	Cd, 20; Fe, 60; Ne, 12.
G 1385.....	10	Ni	Cd, 30; Fe, 60; Ne, 12.
G 1398.....	3	Ag	Cd, 50; Fe, 60; Fe, 5; Ne, 15.
G 1399.....	5	Ag	Cd, 35; Fe, 60; Fe, 3; Ne, 10.
G 1400.....	7.5	Ag	Cd, 30; Fe, 70; Fe, 3; Ne, 10.
G 1401.....	7.5	Ag	Cd, 20; Fe, 90; Fe, 5; Ne, 12.
G 1402.....	10	Ag	Cd, 20; Fe, 90; Fe, 1.5; Ne, 10.
G 1403.....	15	Ag	Cd, 25; Fe, 90; Fe, 1.5; Ne, 12.
G 1404.....	5	Ag	Ne, 10; Fe, 80; Fe, 1.5; Ne, 10.
G 1405.....	3	Ag	Ne, 15; Fe, 70; Fe, 1.5; Ne, 20.
G 1417.....	10	Ag	Fe, Ne, simultaneously, 40.
G 1418.....	10	Ag	Fe, Ne, simultaneously, 60.
G 1419.....	10	Ag	Fe, Ne, simultaneously, 5, 60.
G 1420.....	7.5	Ag	Fe, Ne, simultaneously, 1, 60.
G 1439.....	7.5	Ag	Fe, Ne, simultaneously, 65.
G 1440.....	7.5	Ag	Fe, Ne, simultaneously, 60.
G 1441.....	7.5	Ag	Fe, Cd, simultaneously, 60.
G 1442.....	7.5	Ag	Fe, Ne, simultaneously, 75.
G 1444.....	5	Ag	Fe, Cd, simultaneously, 75.
G 1446.....	3	Ag	Fe, Cd, simultaneously, 60.

The general theory of the classical étalon interferometer method of Fabry and Perot<sup>10</sup> for wave-length comparisons is so well known, both as to the arrangement of apparatus and reduction of the results, that it does not require repetition here. Details

<sup>10</sup> Ann. de Chim. et. de Phys., 25, p. 110; 1902.

about the particular apparatus and procedure involved in the present investigation have already been given above and the following remarks on measurements, computations, and corrections should suffice. In general, the diameters of two interference rings were measured for each standard line, the innermost ring either being avoided if its fractional order was less than 0.4 or being supplemented by observations on the third ring. Several of the plates were reduced from measurements of three rings for each line. The computations were made by means of the formula

$$\lambda_1 = \frac{\lambda P}{P_1} \left( 1 + \frac{d^2}{8R^2} - \frac{d_1^2}{8R^2} \right)$$

in which  $\lambda_1$  represents the wave length of a secondary standard to be ascertained in terms of  $\lambda$ , the wave length of the primary standard,  $P_1$  and  $P$  are, respectively, the orders of interference producing the first ring in each case,  $d_1$  and  $d$  represent the linear diameters of these two rings, respectively, and  $R$  is the focal length of the lens which focuses the interference rings on the slit of the spectrograph. Small corrections required by deviation of the observing conditions from the standard temperature and atmospheric pressure were made according to the Bureau of Standards tables,<sup>11</sup> which have been adopted for this purpose by the International Astronomical Union. The corrections for the so-called dispersion of phase change were determined from étalons of various sizes<sup>12</sup> and were confirmed by a supplementary set of observations on neon and mercury lines for which étalons up to 25 mm in length were used.

### III. RESULTS.

The original recommendation in establishing an international system of standard wave lengths was that secondary standards be determined by an interference method at intervals of 50 Angstroms, and that tertiary standards be derived from these by interpolation. Since the labor involved in measuring wave lengths directly in terms of the primary standard is not much greater than that required for the same precision by interpolation, we have in the present work measured lines at closer intervals. In Table 2 we present results for 159 lines, including 84 of the international secondary standards, in the spectral range 3370 to 6678 Å, thus

<sup>11</sup> B. S. Bull., 14, p. 728; 1918.

<sup>12</sup> B. S. Bull., 12, p. 199; 1915.

giving standards at intervals which average about 20 Å. Column 1 in Table 1 describes each line as to intensity, group, and class, the relative intensities being the estimates of Burns,<sup>13</sup> while the data on group and class, as far as these are available, are taken from Gale and Adams,<sup>14</sup> and additional group classifications by St. John and Babcock.<sup>15</sup>

The wave lengths resulting from direct comparison with the primary standard are found in column 2, followed by the number of observations and the probable error for each value. "A" indicates a probable error less than 0.0007 Å, "B" corresponds to a probable error between 0.0007 Å and 0.0012 Å, while "C" means that the determination is poor. For comparison with column 2, column 5 contains the fractional values of the international secondary standards and column 6 the interpolated values and tertiary standards adopted by the International Astronomical Union.<sup>16</sup>

With respect to the choice of standards, the International Astronomical Union has expressed itself as follows:<sup>17</sup>

It is very desirable to eliminate as far as possible the unstable standards belonging to groups c 5 and d. The list of proposed tertiaries shows that stable Fe lines are available as soon as their wave lengths are referred directly to the red cadmium line, except for the short gap between 4700 and 4800 Å and for the region 5500–6000 Å. This long gap can be partially filled by neon lines, whose wave lengths have been referred to the red cadmium line by three observers, and this entire gap as well as that at 4750 Å can be filled with good solar lines, when their wave lengths in integrated sunlight have been determined by a sufficient number of interferometer observations.

It should be emphasized, however, that no solar spectrum standards on the new international scale are, as yet, available, and that not all laboratories have access to the solar spectrum. Furthermore, it is conceivable that in some cases the use of a neon tube requiring different electrical facilities than the iron arc, may be inconvenient. Since the neon lines fill only one-third of one of the gaps mentioned above, it is perhaps doubtful if the neon tube will be very generally employed to supplement the iron arc. For these reasons we believe that it is highly desirable to make the iron arc serve, as far as possible, as a source of standards for the entire range of wave lengths, and we have, therefore, in our measurements, included 17 lines of group c, 22 of group d, and 3 of group e to fill the spectral regions, either because no other iron lines are available there or to distribute the standards more evenly. Ac-

<sup>13</sup> Lick Observatory Bulletin No. 247, also *Zeit. f. Wiss. Phot.*, 12, p. 209; 1912.

<sup>14</sup> *Astroph. Jour.*, 35, p. 10; 1912; also, *Astroph. Jour.*, 37, p. 391; 1913.

<sup>15</sup> *Astroph. Jour.*, 53, p. 260; 1921.

<sup>16</sup> *Trans. I. A. U.*, 1, p. 41; 1922.

<sup>17</sup> *Ibid.*, p. 38.

ording to our experience any and all of these values are strictly reproducible under the same observing conditions and may be used with confidence in precision measurements of lengths.

TABLE 2.—Standard Wave Lengths in the Iron Arc Spectrum.

Intensity, group and class.	λ B. S.	Num- ber of obser- vations.	Prob- able error.	Sec- ondary stand- ards.	Inter- po- lated.	Intensity, group and class.	λ B. S.	Num- ber of obser- vations.	Prob- able error.	Sec- ondary stand- ards.	Inter- po- lated.
6.....	3370.786	9	A	789	788	5 c 4.....	4494.568	25	A	572	571
6.....	3399.337	13	A	337	337	2.....	4517.529	4	B	.....	532
6.....	3428.196	11	A	.....	.....	7 c 4.....	28.619	15	A	.....	622
4.....	3445.151	18	A	154	153	5 b 3.....	31.152	24	A	155	155
6.....	3485.343	11	A	345	343	3 b.....	47.851	16	A	853	854
5.....	3513.821	11	A	821	821	2.....	74.725	3	C	.....	.....
4.....	27.796	6	B	.....	.....	4.....	4592.655	21	A	658	657
6.....	56.882	13	A	881	881	4.....	4602.945	26	A	947	946
5.....	58.517	3	C	.....	.....	5 b.....	25.054	14	A	.....	.....
4.....	3575.374	10	A	.....	.....	4 b.....	47.437	22	A	439	439
5.....	3606.683	24	A	682	682	5 c 4.....	78.853	17	A	.....	856
5.....	23.188	20	A	.....	.....	4 c 4.....	4591.414	18	A	417	417
6.....	40.392	28	A	392	392	5 c 5.....	4707.282	19	A	288	290
4.....	76.315	20	A	313	313	3 b.....	10.287	17	A	.....	288
6.....	77.631	20	A	629	629	3 a.....	33.596	12	A	.....	598
3.....	3695.055	18	A	.....	.....	5 c 5.....	36.782	24	A	786	790
5.....	3704.464	3	C	.....	.....	3 b.....	41.533	8	A	.....	535
6.....	24.381	30	A	380	380	3 b.....	72.818	8	B	.....	818
5.....	53.615	31	A	615	615	3 b.....	4789.654	18	A	657	656
5.....	3785.955	9	B	.....	.....	5 c 5.....	4859.748	23	A	758	759
6.....	3805.346	24	A	346	346	5 c 5.....	4878.219	22	A	225	224
5.....	43.261	22	A	261	260	5 c 5.....	4903.317	21	A	325	326
6.....	65.526	8	B	527	527	8 c 5.....	19.001	25	A	007	008
4.....	73.764	16	A	.....	.....	3 a.....	24.775	11	A	.....	776
4 b.....	3891.932	8	A	.....	.....	3 a.....	39.692	13	A	.....	691
5 a 1.....	3906.483	10	B	482	483	5 c 5.....	66.097	15	A	104	105
3 b.....	07.938	18	A	937	937	3 a.....	4994.132	17	A	.....	135
4 b.....	35.816	22	A	818	817	5 c 5.....	5001.872	21	A	881	881
4 b.....	49.958	21	A	.....	.....	4 a.....	12.072	23	A	073	073
5 b 4.....	77.744	24	A	746	746	4 a.....	41.758	19	A	.....	760
6 b 4.....	3997.397	3	C	.....	.....	5 a.....	49.825	20	A	827	827
5 a.....	4009.716	20	A	.....	.....	4 c.....	68.774	12	A	.....	.....
5 b.....	21.870	24	A	872	872	4 a.....	5083.343	18	A	344	343
3.....	74.789	21	A	.....	.....	4 a.....	5110.414	19	A	415	415
5 b.....	76.636	12	A	642	638	4 a.....	23.722	16	A	.....	725
3 b.....	4095.974	19	A	.....	.....	3 a.....	27.362	14	A	.....	365
5 b.....	4107.492	26	A	.....	.....	4 a.....	50.843	15	A	.....	845
6 b.....	18.549	23	A	552	552	8 a 4.....	67.490	24	A	492	493
5 b 4.....	34.680	21	A	685	684	7 c.....	91.462	20	A	.....	.....
4 b.....	47.673	24	A	676	675	8 d.....	92.353	22	A	363	360
4 b.....	56.802	25	A	.....	.....	4 a.....	5198.715	15	A	.....	715
4 b.....	75.639	19	A	.....	.....	5 a.....	5202.339	19	A	.....	340
4 b.....	84.894	26	A	.....	.....	5 a.....	16.277	22	A	.....	280
6 d.....	4191.436	20	A	443	444	8 d 5.....	32.948	23	A	957	956
3 b 3.....	4203.986	23	A	.....	.....	4 a.....	42.496	9	B	.....	496
5 b.....	19.364	23	A	.....	.....	3.....	50.650	12	A	.....	652
6 d 5.....	33.609	20	A	615	614	8 d 5.....	66.564	26	A	569	571
2 b.....	45.260	19	A	.....	.....	8 a 4.....	70.361	11	A	.....	360
2 b.....	67.831	13	A	.....	.....	7 d.....	5283.629	20	A	.....	.....
6 b 1.....	82.406	23	A	408	408	5 d.....	5302.308	18	A	315	315
2.....	4298.040	3	A	.....	.....	2 a.....	07.364	12	A	.....	365
5 b 3.....	4315.087	20	A	089	090	6 d 5.....	24.187	23	A	196	196
5 b 3.....	37.049	21	A	.....	.....	4 a 4.....	28.532	9	C	.....	537
4 b 3.....	52.738	23	A	741	740	5 a 4.....	41.026	24	A	.....	028
5 a 3.....	75.932	22	A	934	934	7 a 1.....	71.493	26	A	495	495
3 b.....	4390.954	14	A	.....	.....	6 a 4.....	5397.131	19	A	.....	134
4 c 4.....	4408.419	16	A	.....	.....	6 a 4.....	5405.778	26	A	780	780
5 a 3.....	27.312	24	A	314	314	6 a 4.....	34.527	28	A	527	528
5 c 4.....	47.722	20	A	.....	.....	6 a 4.....	55.613	22	A	614	615
5 b 4.....	66.555	26	A	556	556	3 d.....	73.908	6	B	.....	.....

TABLE 2.—Standard Wave Lengths in the Iron Arc Spectrum—Continued.

Intensity, group, and class.	$\lambda$ B. S.	Num- ber of obser- vations.	Prob- able error.	Sec- ond- ary stand- ards.	Inter- po- lated.	Intensity, group, and class.	$\lambda$ B. S.	Num- ber of obser- vations.	Prob- able error.	Sec- ond- ary stand- ards.	Inter- po- lated.
4 a 3.....	5497.520	22	A	522	522	5 b 4.....	6191.564	22	A	568	568
4 a 3.....	5506.783	23	A	784	784	3 b 4.....	6219.287	11	A	290	
5 d 5.....	69.627	21	A	633	-----	5 b 4.....	30.730	23	A	734	734
6 d 5.....	5586.764	24	A	772	-----	4 b 4.....	52.562	15	A	567	567
6 d 5.....	5615.653	23	A	661	-----	3 b 4.....	65.140	14	B	145	145
5 d 5.....	24.551	15	B	-----	-----	3 b 4.....	6297.800	6	A	-----	803
4 d 5.....	58.827	20	A	836	-----	5 d 5.....	6301.514	18	A	-----	
3 d.....	5662.526	8	B	-----	-----	4 b 4.....	18.024	16	A	028	028
3.....	5701.554	10	A	-----	-----	4 b 4.....	35.338	18	A	341	342
3 d.....	09.388	16	A	396	-----	5 b 4.....	6393.607	22	A	612	612
3 d.....	53.131	6	B	-----	-----	5 d 5.....	6400.014	4	B	-----	
4 d.....	5763.002	15	B	013	-----	5 d 5.....	11.662	4	C	-----	
4 e.....	5862.354	5	B	-----	-----	4 b 4.....	21.355	17	A	-----	362
6 e.....	5914.172	3	A	-----	-----	5 b 4.....	30.853	22	A	859	859
4.....	5934.668	6	C	-----	-----	5 b 4.....	6494.987	24	A	993	993
4 e.....	6024.066	14	A	-----	-----	5 b 4.....	6546.247	18	A	252	252
2 b 4.....	27.058	6	A	059	059	5 b 4.....	6592.920	16	A	928	927
4 b 4.....	6065.489	20	A	492	492	4 b.....	6663.447	6	B	-----	455
4 b 4.....	6136.623	6	C	-----	624	5 b 4.....	6677.994	17	B	8.004	8.001
4 b 4.....	37.697	21	A	701	702						

## IV. DISCUSSION.

Table 2 shows, first of all, that the values for c and d lines as derived from the long arc are distinctly smaller than the adopted secondaries, thus confirming in a qualitative way the results of St. John and Babcock, who found that the lines of groups c and d were displaced with respect to the lines of groups a and b. For 23 lines belonging to groups c and d the secondary standards minus our new values averages  $+0.0072$  Å.

It is also evident that there is a systematic difference for the remaining lines, 44 of which have been recognized as belonging to groups a and b. The difference between the international values and our redeterminations averages  $+0.0029$  Å for these 44 lines. We have searched diligently for an explanation of this divergence, but are unable to account for it in an entirely satisfactory manner. It was suspected that at least a part of the difference might be ascribed to a change in wave length of a and b lines when these are derived from the long arc instead of from the short one, which served as a source for the internationally adopted measurements. An independent investigation on standards among the longer waves of iron was made recently with a 6-mm 6-ampere arc.<sup>18</sup> Omitting poor determinations, 34 lines with group designations are common to these two sets of measurements; these are given in Table 3 for purposes of comparison. Ten lines of group d average

<sup>18</sup> B. S., Sci. Papers, No. 479.

0.0047 Å longer in the shorter arc, but the average value for 22 lines of groups a and b is only 0.0004 Å greater in the shorter arc. In other words, the new measurements with the short arc deviate from the so-called stable international standards by nearly the same amounts as the redeterminations from the new arc, indicating that the modifications in the arc do not change these values more than a few ten-thousandths of an Angstrom.

TABLE 3.—New Values from Long and Short Arcs Compared with Secondaries.

Intensity, group, and class.	12-mm 5-ampere arc.	6-mm 6-ampere arc.	Secondaries.	Intensity, group, and class.	12-mm 5-ampere arc.	6-mm 6-ampere arc.	Secondaries.
6 a 4.....	5434.527	525	527	3 b 4.....	6219.287	286	.....
6 a 4.....	55.613	614	614	5 b 4.....	30.730	730	734
4 a 3.....	5497.520	520	522	4 b 4.....	52.562	564	.....
4 a 3.....	5506.783	782	784	3 b 4.....	65.140	140	145
5 d 5.....	67.627	631	633	3 b 4.....	6297.800	800	.....
6 d 5.....	5586.764	770	772	5 b 5.....	6301.514	515	.....
6 d 5.....	5615.653	658	661	4 b 4.....	18.024	025	028
5 d 5.....	24.551	555	.....	4 b 4.....	35.338	338	341
4 d 5.....	58.827	834	836	5 b 4.....	6393.607	608	612
3 d.....	5662.526	529	.....	5 d 5.....	6400.014	018	.....
3 d.....	5709.388	392	396	4 b 4.....	21.355	356	.....
3 d.....	53.131	138	.....	5 b 4.....	30.853	853	859
4 d.....	5763.002	009	013	5 b 4.....	6494.987	988	993
4 e.....	6024.066	060	.....	5 b 4.....	6546.247	247	252
4 b 4.....	6065.489	489	492	5 b 4.....	6592.920	922	928
2 b 4.....	37.697	699	701	4 b.....	6663.447	447	.....
5 b 4.....	6191.564	565	568	5 b 4.....	6677.994	994	8.004

Considering the circumstances under which the original observations were made, we have been forced to the conclusion that the adopted system of international secondary and tertiary standards may be slightly in error. As stated before, the wave-length comparisons upon which the international standards are based were made before the effects of certain variations in operating conditions of the sources were appreciated or quantitatively determined. The so-called pole effect in the iron arc is an example of the resulting uncertainty in a wave length when the source is not accurately described. Similar uncertainty may exist for the cadmium standard when the original source which defined the unit of wave length (International Angstrom unit) is not adhered to. In all of our work on secondary standards we have used, as the primary standard, the low vapor-pressure cadmium tube, whose red radiation was measured relative to the meter, and our experience with this source indicates that the wave length of the red line is constant and reproducible well within the limiting precision attainable in wave-length comparisons.<sup>19</sup>

<sup>19</sup> B. S., Sci. Papers, 18, p. 188; 1922.

It is to be regretted that other laboratories have not made more use of this source, and it is, perhaps, a serious matter that none of the measurements on which the international system was based were made directly from the primary standard as defined. Fabry and Buisson<sup>20</sup> in measuring 115 iron lines (2374 to 6495 Å) referred these to an auxiliary standard (5460.741 Å) from the mercury spectrum as emitted by a Cooper-Hewitt lamp. This line is known to have a very complex fine structure and its effective wave length in interferometers is, therefore, highly irregular.<sup>21</sup> Eversheim<sup>22</sup> employed the Heraeus arc lamp, which contained a cadmium amalgam and was operated with 4.5 amperes on a 220-volt circuit. Furthermore, the complex blue line (5085.822 Å) was often used instead of the red line (6438.4696 Å). A similar cadmium arc and procedure was employed by Pfund.<sup>23</sup>

Discrepancies and systematic differences, exceeding the probable errors, exist among these first determinations.<sup>24</sup> For example, the standard 6678.004 Å is based upon the observations 8.000, 8.004, and 8.008 Å, while our value from either the short or the long arc is 6677.994 Å.

It may, therefore, be questioned if the adopted system of secondary standards is in a sufficiently satisfactory condition, since it is not based on the strictly defined primary standard, and the values were obtained before detailed specifications for the iron arc existed. The accuracy of both absolute and relative values might be increased by remeasurement with the long arc which gives somewhat sharper lines. In our opinion, it is highly desirable to have a system of international standards of wave length determined as accurately as possible, and strictly according to the logical definitions of such a system.

WASHINGTON, August 20, 1923.

<sup>20</sup> *Astroph. Jour.*, 28, p. 169; 1908.

<sup>21</sup> Perard, *Comptes Rendus.*, 176, p. 1060; 1923.

<sup>22</sup> *Ann. der Phys.*, 30, p. 815; 1909.

<sup>23</sup> *Astroph. J.*, 28, p. 197; 1908.

<sup>24</sup> *Phys. Rev.*, 31, p. 602; 1910.





## INDEX TO VOLUME 19

A		C	
	Page		Page
A quantitative study of regeneration by inductive feed back.....	419	Calculation of inductance.....	641
Aberrations of photographic lenses.....	587	Cathode-ray oscillograph.....	445
Absorption of radio waves.....	193	use in frequency standardization.....	445
spectra. <i>See</i> Spectra.			
Actinoelectrical properties of molybdenite ...	375	<i>Chenault, R. L., Arthur E. Ruark, F. L. Mohler, Paul D. Footh and, Spectra and critical potentials of fifth group elements...</i>	463
Alternating current resistance and inductance of solenoids.....	73	Circuits, radio-frequency, for measurements ..	39
current theory of regeneration.....	419	Coaxial circles, curves for estimating the mutual inductance .....	541
Alloy, iron-carbon, determination of critical ranges by thermoelectric means.....	347	formulas determining mutual inductance.	541
Alloys, determination of iridium in.....	325	mutual inductance of .....	541
platinum.....	325	tables for computation of mutual inductance.....	541
preparation of.....	325		
Aluminum alloys, thermal expansion .....	697	<i>Coblentz, W. W., Some new thermoelectric and actinoelectrical properties of molybdenite ...</i>	375
copper alloys, thermal expansion.....	697	<i>—, and H. R. Fulton, A radiometric investigation of the germicidal action of ultra-violet radiation .....</i>	641
manganese alloys, thermal expansion.....	697	<i>—, and C. W. Hughes, Ultra-violet reflecting power of some metals and sulphides .....</i>	577
copper alloys, thermal expansion.....	697	Coil antenna, transmitting.....	281
silicon alloys, thermal expansion .....	697	Coils, single-layer, alternating-current, resistance and inductance of .....	73
copper alloys, thermal expansion.....	697	Ceramics .....	357
manganese alloys, thermal expansion.....	697	Critical potentials of arsenic, antimony, and bismuth ranges in iron-carbon alloys, determined by thermoelectric means .....	347
thermal expansion.....	697	Crystals .....	307
zinc alloys, thermal expansion.....	697	<i>Curtis, Harvey L., and C. Matilda Sparks, Formulas, tables, and curves for computing the mutual inductance of two coaxial circles ...</i>	541
Amateur, effect of lading on reception by ...	193	<i>—, and Robert C. Duncan, A method for the accurate measurement of short-time intervals .....</i>	17
radio wave finding.....		Curves .....	541
Antenna, airplane, directive receiving properties of .....	281		
double coil .....	281	D	
double coil, directional transmission, characteristics of .....	281	"Dead spots" and radio reception .....	193
loop, transmitting .....	281	Decrement .....	231
Antimony, spectral classifications, critical potentials, and absorption spectra .....	463	<i>Dellinger, J. H., and J. L. Preston, Methods of measurement of properties of electrical insulating materials .....</i>	39
Applications of the interferometer .....	357	<i>—, L. E. Whitemore, and S. Kruse, A study of radio signal lading .....</i>	193
Arc spectrum of molybdenum .....	113	Density, electrical insulating materials, measurement .....	39
Arsenic, spectral classifications, critical potentials, and absorption spectra .....	463	Dielectric constant, insulating materials, measurement .....	39
Atmospheric electricity, relation to radio transmission .....	193	Directional variations of radio signals .....	193
Atmospherics, relation to radio reception .....	193	Directive radio transmission .....	281
		measurements .....	1
		Distortion, radio wave .....	281
		Diurnal variations of radio signals .....	193
		<i>Duncan, Robert C., Harvey L. Curtis and, A method for the accurate measurement of short-time intervals .....</i>	17
B			
Barometric conditions, effect on radio transmission .....	193		
Beacon, radio, directive .....	281		
<i>Bennett, A. H., Aberrations of long focus anastigmatic photographic objectives .....</i>	587		
<i>Berliner, J. F. T., Preparation and properties of pure iron alloys: IV. Determination of the critical ranges of pure iron-carbon alloys by the thermoelectric method .....</i>	347		
Bismuth, spectral classifications, critical potentials, and absorption spectra .....	463		
Brinell hardness numerals, table of .....	39		

	Page
Dunmore, F. W., F. H. Engel and, A directive type of radio beacon and its application to navigation.....	281
—, and Francis H. Engel, Directive radio transmission on a wave length of 10 meters..	1
Duralumin, thermal expansion .....	697
ultra-violet reflecting power.....	577
<b>E</b>	
Electrical properties of insulating materials, measurement.....	39
Einstein.....	307
Energy distribution.....	231
Engel, Francis H., Francis W. Dunmore and, Directive radio transmission on a wave length of 10 meters.....	1
—, and F. W. Dunmore, A directive type of radio beacon and its application to navigation.....	281
Expansion, thermal, aluminum.....	697
molybdenum.....	429
Eye, sensibility.....	131
<b>F</b>	
Fading, effect on radio reception.....	193
theory of.....	193
Flash-over voltage, radio-frequency measurement.....	39
Fog signals, radio.....	281
Foote, Paul D., Arthur E. Ruark, F. L. Mohler, R. L. Chenault and, Spectra and critical potentials of fifth group elements..	463
Formulas.....	541
Four-terminal resistors.....	297
Frequency standardization by means of parallel wires.....	487
Fulton, H. R., W. W. Coblenz and, A radiometric investigation of the germicidal action of ultra-violet radiation.....	641
<b>G</b>	
Galena, ultra-violet reflecting power.....	577
Gero, W. B., Peter Hidner and, Thermal expansion of molybdenum.....	429
Generation of very high frequency currents..	1
Generator for ultra-radio frequency currents.	1
Gibson, K. S., and E. P. T. Tyndall, Visibility of radiant energy'.....	131
Gilchrist, Raleigh, Investigations on the platinum metals: IV. Determination of iridium in platinum alloys by the method of fusion with lead.....	325
Glassspots, thermal expansivities of.....	357
Gold, effect on determination of iridium.....	325
Gravitation.....	307
Graphite, ultra-violet reflecting power.....	577
<b>H</b>	
Hardness, electrical insulating materials, measurement.....	39
Hartmann test for lenses.....	587
Hazen, Grace, and Frieda Kenyon, Primary radio-frequency standardization by use of the cathode-ray oscillograph.....	445
<b>I</b>	
Heaviside layer, influence on radio transmission.....	193
Heyl, Paul R., Gravitational anisotropy in crystals.....	307
Hickman, C. N., Alternating-current resistance of single-layer coils.....	73
Hidner, Peter, Thermal expansion of aluminum and various important aluminum alloys.....	697
—, and W. B. Gero, Thermal expansion of molybdenum.....	429
High-frequency resistance, measurement.....	39
Hughes, C. W., W. W. Coblenz and, Ultra-violet reflecting power of some metals and sulphides.....	577
Humidity control tank.....	39
Hund, August, Theory of determination of ultra-radio frequencies by standing waves on wires.....	487
<b>I</b>	
Impact strength, electrical insulating materials, measurement.....	39
Inductance, alternating current, of solenoids..	73
mutual.....	541
Inductive coupling.....	419
feed back, study of.....	419
Insulating materials, electrical, properties, measurement.....	39
Interference.....	231
Intensity measurements, sound.....	105
Inverse fading of radio signals.....	193
Iridium.....	325
determination in platinum alloys.....	325
spectrographic examination of.....	325
Iron.....	325
arc spectra.....	263
spectrum.....	273
carbon alloys, thermal analysis of thermoelectric method of thermal analysis, separation from iridium.....	347
<b>J</b>	
Jolliffe, C. B., and Miss J. A. Rodman, A quantitative study of regeneration by inductive feed back.....	419
<b>K</b>	
Karcher, J. C., A method for the measurement of sound intensity.....	105
Keirin, Burns, W. F. Meggers, C. C. Kiess and, Determination of secondary standards of wave length from the new international iron arc.....	263
Kenyon, Frieda, Grace Hazen and, Primary radio-frequency standardization by use of the cathode-ray oscillograph.....	445
Kiess, C. C., Series in the arc spectrum of molybdenum.....	113
—, W. F. Meggers, Keirin Burns and, Determination of secondary standards of wave length from the new international iron arc.....	263
—, W. F. Meggers and, Interferometer measurements of the longer waves in the iron arc spectrum.....	273
Kruse, S., J. H. Dellinger, L. E. Whitemore and, A study of radio signal fading.....	193

L	R		
Page	Page		
Lenses, monaxial aberrations.....	587	Radiant energy, visibility of.....	131
Low-resistance measurements.....	297	Radio.....	231
Luminous efficiency of radiant energy.....	131	beacon.....	281
<b>M</b>		fading.....	193
Magnetic, properties and mechanical stress .....	681	frequency properties, insulating materials, measurement .....	39
Measurement of resistance.....	297	standardization.....	445
properties electrical insulating materials .....	39	transmitting set.....	281
Measurements of thermal dilatations.....	357	Reception, radio, on airplanes.....	281
Mechanical properties, electrical insulating materials, measurement.....	39	Reflecting power, pyrites, stibnite, molybdenite, galena, graphite, duralumin.....	577
<i>Meggers, W. F., C. C. Kiess, and Kevin Burns</i> , Determination of secondary standards of wave length from the new international iron arc.....	263	Reflection of radio waves.....	193
<i>and C. C. Kiess</i> , Interferometer measurements of the longer waves in the iron arc spectrum.....	273	of very short electric waves.....	1
<i>Merrill, George E.</i> , Application of the interferometer to measurements of the thermal dilatation of ceramic materials.....	357	Refraction of radio waves.....	193
Meteorological conditions, effect on radio transmission.....	193	Regeneration.....	419
Microstructure, molybdenum.....	429	Resistance, alternating-current, of solenoids..	73
<i>Mohler, F. L., Arthur E. Ruark, Paul D. Foote, R. L. Chenault, and</i> , Spectra and critical potentials of fifth group elements...	463	measurements.....	297
Moisture absorption, electrical insulating materials, measurements.....	39	radio-frequency, measurement.....	39
Molybdenite, thermoelectrical and actino-electrical properties.....	375	variation method, radio measurements..	39
ultra-violet reflecting power.....	577	Resistivity, insulating materials, measurement.....	39
Molybdenum, series in the arc spectrum of..	113	Rhodium, effect on determination of iridium.....	325
thermal expansion.....	429	<i>Rodman, Miss J. A., C. B. Jolliffe and</i> , A quantitative study of regeneration by inductive feed back.....	419
Mutual inductance calculations.....	641	<i>Ruark, Arthur, F. L. Mohler, Paul D. Foote, and R. L. Chenault</i> , Spectra and critical potentials of fifth group elements.....	463
of circular circuits.....	641	Ruthenium, effect on determination of iridium .....	325
of circular filaments.....	641	S	
of coaxial circles .....	541	Safety, method of improvement in aerial and marine navigation.....	281
determinations.....	541	<i>Sanford, R. L.</i> , Effect of stress on the magnetic properties of steel wire.....	681
<b>N</b>		Screen, shielding, radio measurements.....	39
Navigation, aerial, radio, aid to.....	281	Seasonal variation of radio signals.....	193
marine, radio, aid to.....	281	Sensibility of eye.....	131
Nitrogen, spectral classifications.....	463	Series in molybdenum.....	113
Nocturnal variation of radio signals.....	193	Shielding, radio measuring circuits.....	39
<b>O</b>		Short-time intervals.....	17
Oscillograph, cathode-ray.....	445	Short-wave directive transmission.....	1
<b>P</b>		Short waves, susceptibility of lading.....	193
Palladium, effect on determination of iridium.....	325	Signal, radio, effect of fading.....	193
Parabolic reflector for directive transmission.....	1	strength, variation of.....	193
Parallel wire system.....	487	<i>Smith, Alva, Frank Wenner and</i> , Measurement of low resistance by means of the Wheatstone bridge.....	297
Photographic lenses, aberrations.....	587	<i>Snow, Chester</i> , Spectroradiometric analysis of radio signals .....	231
Power loss, electrical insulating materials, measurement.....	39	Solenoids, alternating-current, resistance and inductance of.....	73
Poynting clamp.....	307	Sound intensity measurements.....	105
<i>Preston, J. L., J. H. Dglinger and</i> , Methods of measurement of properties of electrical insulating materials.....	39	<i>Sparks, C. Matilda, Harvey L. Curtis and</i> , Formulas, tables, and curves for computing the mutual inductance of two coaxial circles.....	541
Primary radio-frequency standardization.....	445	Specimens, electrical insulating materials, preparation.....	39
by use of the cathode-ray oscilloscope.....	445	Spectra, spectral classifications, and excitation of spectra of arsenic, antimony, bismuth, and nitrogen.....	463
standard wave meters.....	445	Spectrum analysis.....	231
wave meter standardization.....	445	visibility of radiant energy in.....	131
Progressive fading of radio signals.....	193		
Pyrites, ultra-violet reflecting power.....	577		

	Page	Page	
Standard wave meter, Bureau of Standards..	445	<i>Tyndall, E. P. T., K. S. Gibson and, Visibility of radiant energy.....</i>	131
Standardization, radio-frequency .....	445		
Standards of wave length.....	263, 273	<b>U</b>	
Standing waves on wire .....	487	Ultra-radio frequencies, determination of .... frequency directive transmission.....	487
Steel wire, effect of stress on magnetic properties.....	681	Ultra-violet reflecting power, pyrites, stibnite, molybdenite, graphite, galena, duralumin .....	577
Stibnite, ultra-violet reflecting power.....	577		
Strays, relation to radio reception.....	193		
Stress, effect on magnetic properties of steel wire.....	681		
Sunrise and sunset, effect on radio transmission.....	193	Vegetation, effect on signal intensity.....	193
Swinging, effect of reception of signals.....	193	Verilite, thermal expansion.....	697
		Visibility of radiant energy.....	131
		Volume resistivity, measurement.....	39
<b>T</b>			
Tables for computing mutual inductance....	541	<b>W</b>	
the calculation of inductance .....	641	Wave length .....	263, 273
Tensile strength, electrical insulating materials, measurement .....	39	relation to fading .....	193
Terra cottas, thermal expansivities of.....	357	meter standardization .....	445
Terrestrial magnetism, relation to radio signals.....	193	transmission phenomena .....	193
Testing, electrical insulating materials.....	39	Waves, standing, on wires.....	487
Thermal expansion, aluminum .....	697	Weather, effect on radio transmission .....	193
aluminum alloys .....	697	<i>Wenner, Frank, and Alva Smith, Measurement of low resistance by means of the Wheatstone bridge .....</i>	297
electrical insulating materials, measurement .....	39	Wheatstone bridge .....	297
molybdenum .....	429	<i>Whittlemore, L. E., J. H. Dellinger, S. Kruse, and, A study of radio signal fading .....</i>	193
of clays and glazes .....	357	Wire, steel, effect of stress on magnetic properties.....	681
expansivities .....	357	Wind drift indicator for aerial navigators....	281
Time measurement of short-time intervals...	17		
Tuning fork, use as fundamental for radio-frequency standardization .....	445	<b>Z</b>	
		Zone, equisignal as an aid to navigation....	281













